R. Overzier

Extreme Starburst Galaxies as Nearby Analogs of High Redshift Lyman Break Galaxies

Starburst galaxies are important for our understanding of galaxy evolution at all redshifts. I will present and discuss the latest results from our ongoing survey of "Local Analogs of Lyman Break Galaxies". Because these starbursts are similar to typical UV-selected starbursts at high redshift in most of their observed and physical properties, we have an excellent training set for understanding the relation between massive star formation, ISM, host galaxy structures, and nuclei of starbursts. In this talk, I will highlight three of our most recent results:

(1) The nearby sample shows a deviation from the so-called IRX-beta relation that is widely used to infer the ratio of total IR-to-UV luminosities at high redshift. This offset is similar to that found for a few lensed LBGs that have direct detections in the IR. I will show how an improved understanding of the IRX-beta relation directly affects estimates of the cosmic star formation rate history.

(2) The LBG analogs at low redshift and LBGs at high redshift display a range in structures from compact to clumpy that is different from typical local star-forming galaxies. Recent studies have suggested that, at least at high redshift, intense star formation is triggered by massive gas accretion in the form of cold flows. Based on a detailed comparison with the morphologies of LBGs in the Hubble Ultra Deep Field, we conclude, however, that starbursts triggered by mergers remain a viable mechanism for driving the evolution of these starbursts.

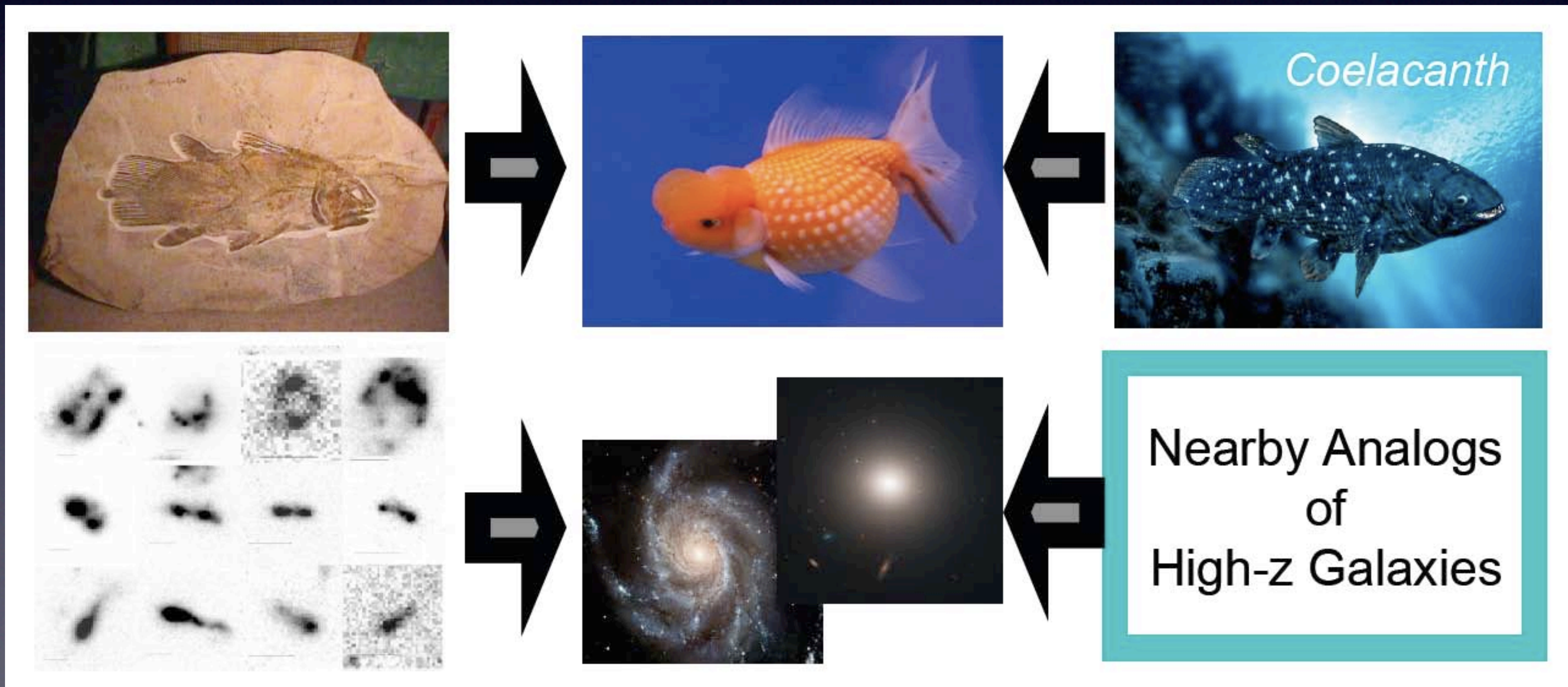
(3) Some of the local starbursts display peculiar nuclei that are more massive and more dense than any central star cluster observed to date. We speculate that they are progenitors of the central cusps in low-mass ellipticals being formed in dissipative mergers. The massive, dense nuclei provide an ideal environment for the formation of black holes. New radio and X-ray data suggest the presence of 10^5-10^6 Msun black holes.

Extreme Starburst Galaxies as Nearby Analogs of High Redshift Lyman Break Galaxies

RODERIK OVERZIER

MAX-PLANCK INSTITUTE FOR ASTROPHYSICS

WITH: TIM HECKMAN (JHU), GALEX SCIENCE TEAM (PI: CHRIS MARTIN), LEE ARMUS, AND MANY OTHERS



Extreme UV-selected Starburst Galaxies

Talk Overview

1. Introduction / Motivation

2. Lyman Break Analogs Sample Properties

3. Some Applications
   - Morphologies at high redshift
   - Formation of compact nuclear objects
   - Calibration of Dust/SFR indicators

4. Summary / Conclusion

Motivation

Lyman Break Galaxies (LBGs)

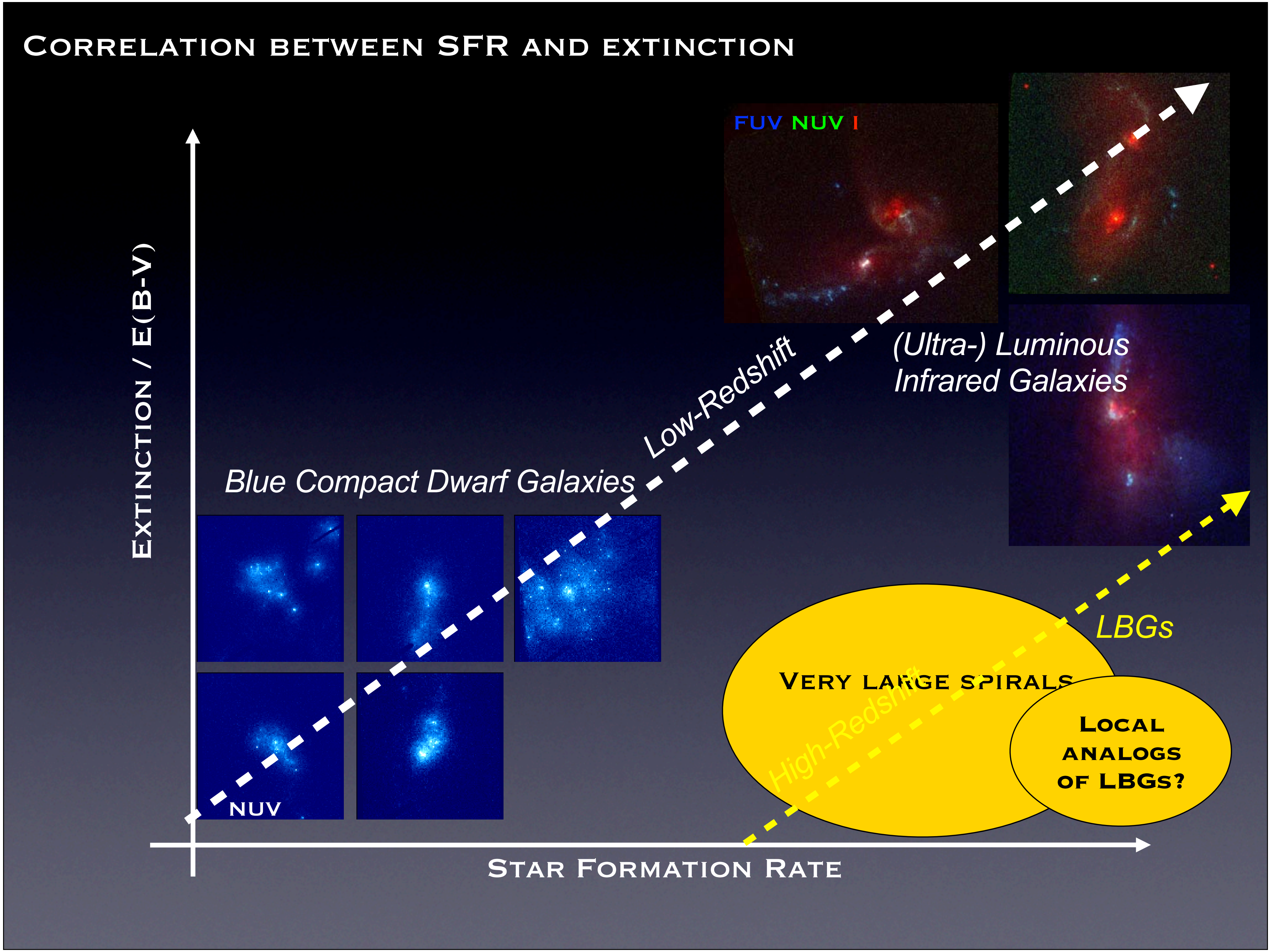
- dominant star forming population at high redshift ($2<z<10$)
- easily selected in the UV due to little dust
- evolution: gas cooling, accretion, outflows and mergers
- must contain seed black holes

Local Starbursts

- Ordinary late-type galaxies (too large, too low SFR)
- BCDs (right metallicity and dust, but too low SFR)
- (U)LIRGs (right SFR, but too much dust, metals, mass)

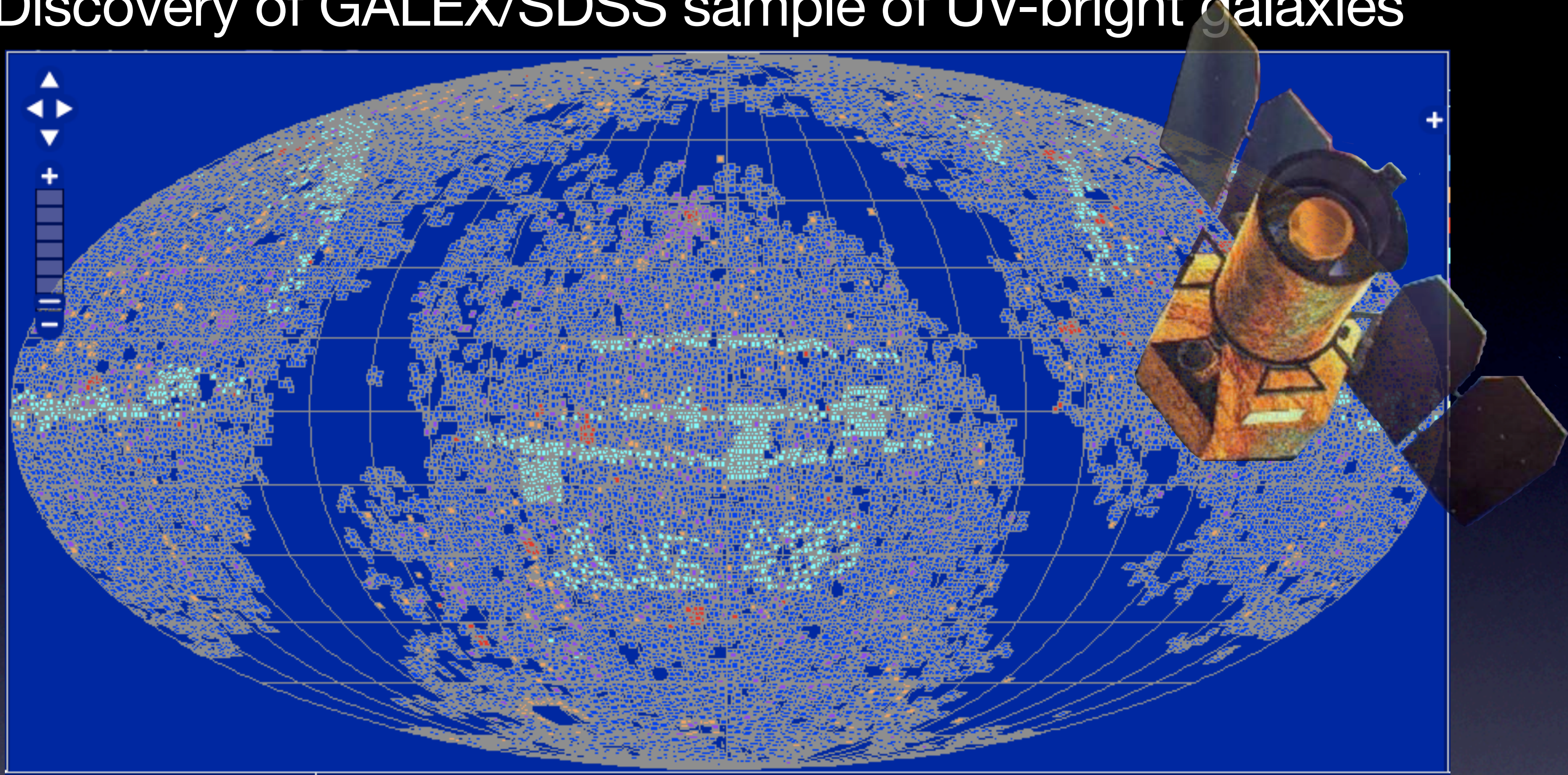
We could learn from a more similar sample of "local analogs"

- not affected by cosmological SB dimming (~250x for z=3)
- spatial resolution (~1 kpc at z=2 to ~200 pc at z=0.1)
- multi-wavelength approach



Correlation between SFR and extinction
FUV NUV I
(Ultra-) Luminous
Infrared Galaxies
Low-Redshift
Blue Compact Dwarf Galaxies
Extinction / E(B-V)
LBGs
Very large spirals
High-Redshift
Local
analogs
of LBGs?
NUV
Star Formation Rate

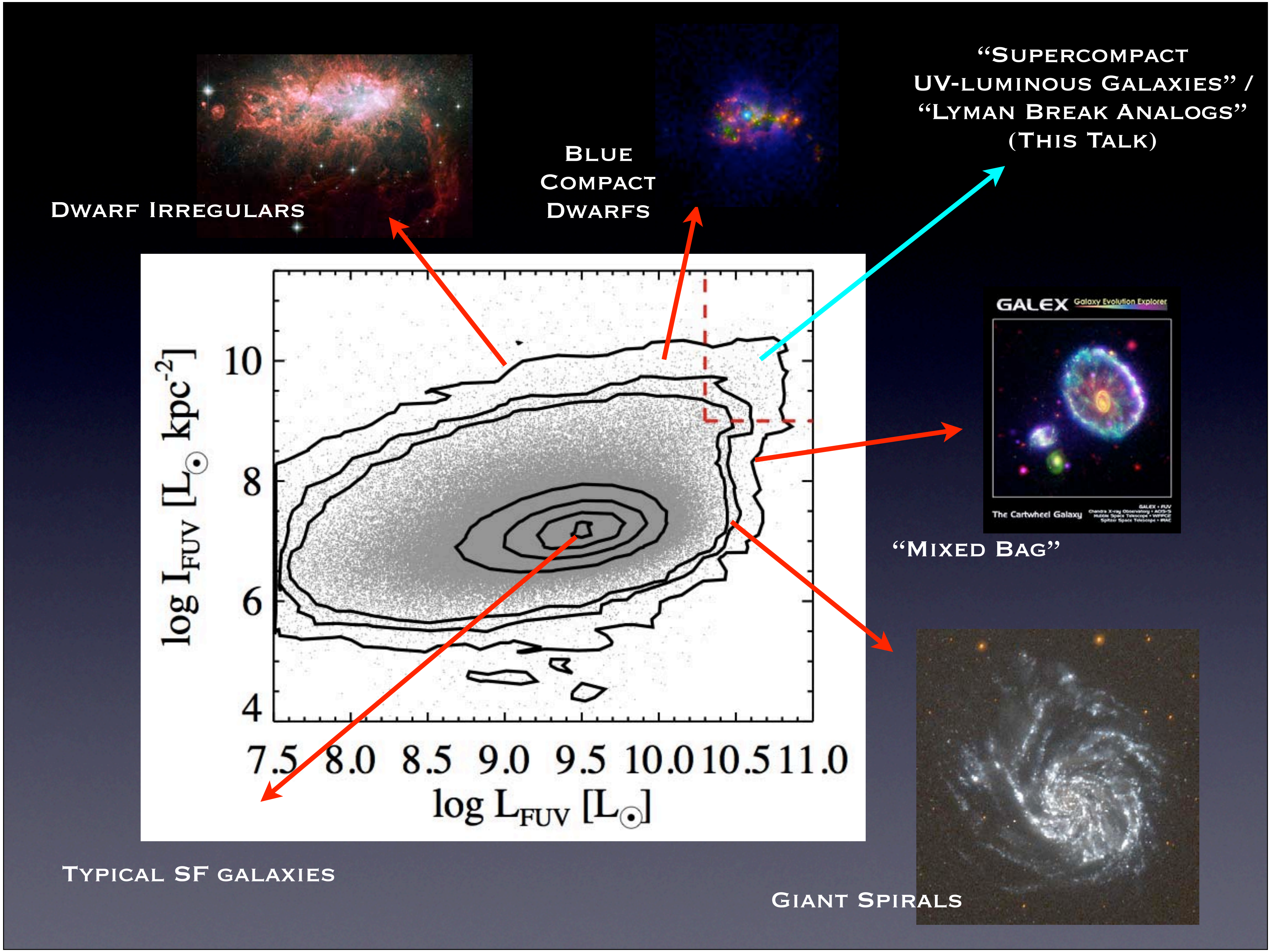
Discovery of GALEX/SDSS sample of UV-bright galaxies



GALEX UV survey + SDSS spectroscopic survey (now 700,000 objects) allows us to search for highly rare outliers <0.1%

Matching typical characteristics of LBGs at high redshift:

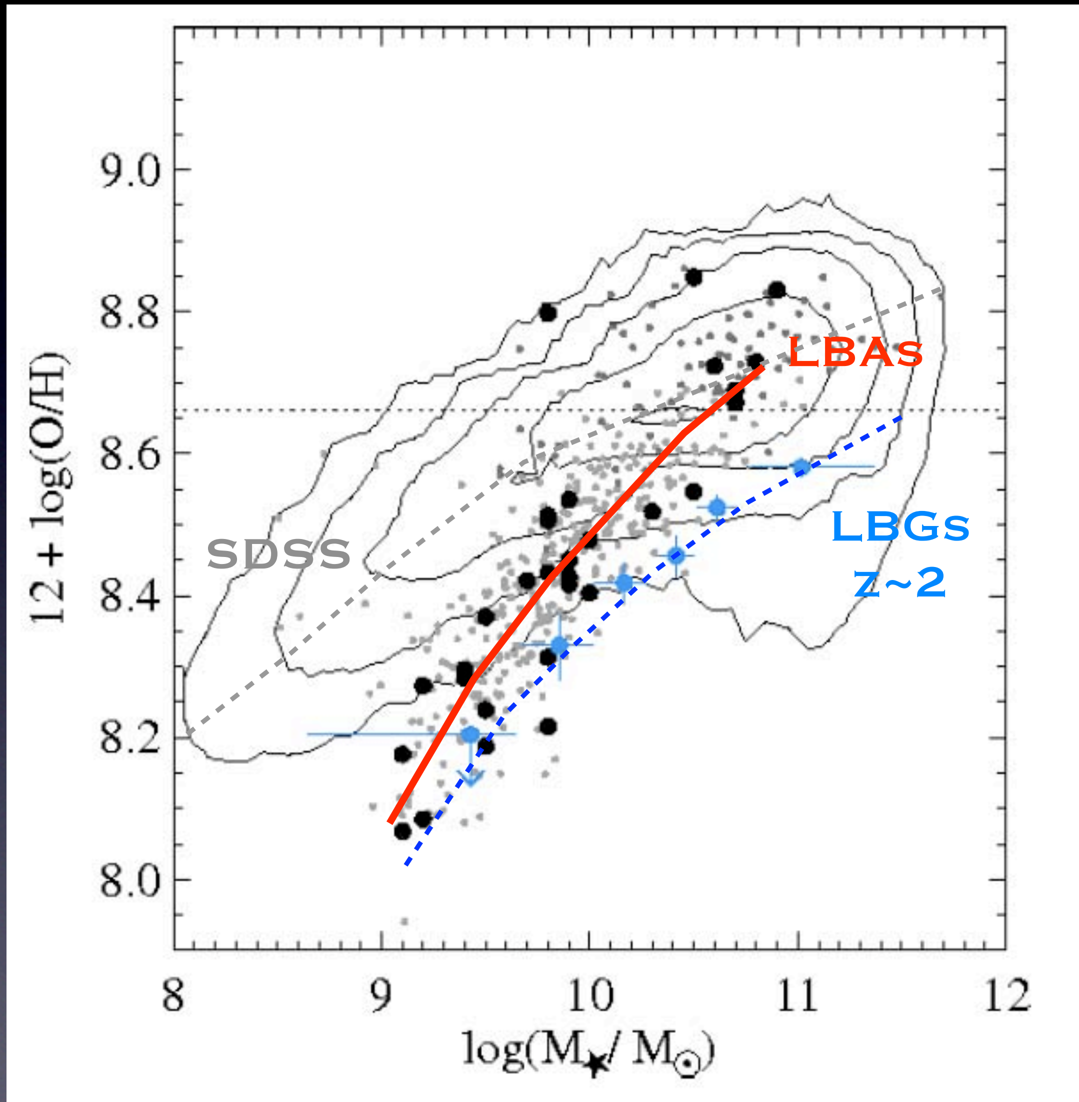
search for objects at z<0.3 with a large *far-UV luminosity* (high SFR, little dust) AND a large *far-UV surface brightness* (compactness)


DWARF IRREGULARS
BLUE COMPACT DWARFS
“SUPERCOMPACT UV-LUMINOUS GALAXIES” / “LYMAN BREAK ANALOGS” (THIS TALK)
GALEX Galaxy Evolution Explorer
The Cartwheel Galaxy
“MIXED BAG”
10
8
6
4
log I_{FUV} [$L_\odot$ kpc^{-2}]
7.5 8.0 8.5 9.0 9.5 10.0 10.5 11.0
log L_{FUV} [$L_\odot$]
TYPICAL SF GALAXIES
GIANT SPIRALS

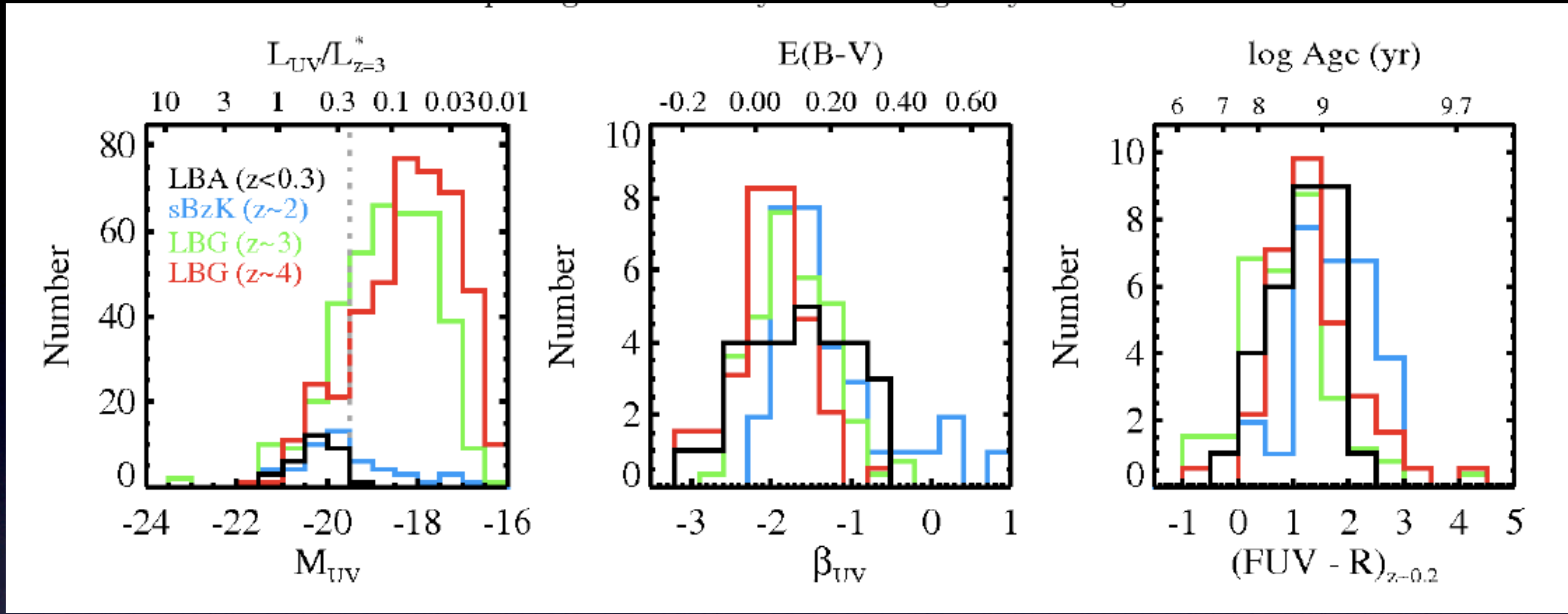
Sample Properties

- Starburst galaxies at $0.1 < z < 0.3$
- UV half-light radius of 1-2 kpc [Ferguson et al. 2004]
- UV-optical colors 0<FUV-R<2 [Shapley et al. 2003]
- metallicity $0.2Z_o$-Z_o [Pettini et al. 2001]
- dust attenuation, E(B-V)=0-0.3 mag [Bouwens et al. 2006]
- stellar masses of ~$10^{9.5}$ -10^{11} M_o [Papovich et al. 2003]
- SFRs of 10-100 M_o yr^{-1} [Reddy et al. 2006,2010]
- gas velocity disp. of 60-130 km s^{-1} [Erb et al. 2006]
- BPT offsets (high ionization) [Shapley et al. 2005]
- morphologically similar to LBGs [Lotz et al. 2004, 2006]
- kinematically similar (in Hα/Pa-α) [Law et al. 2009]

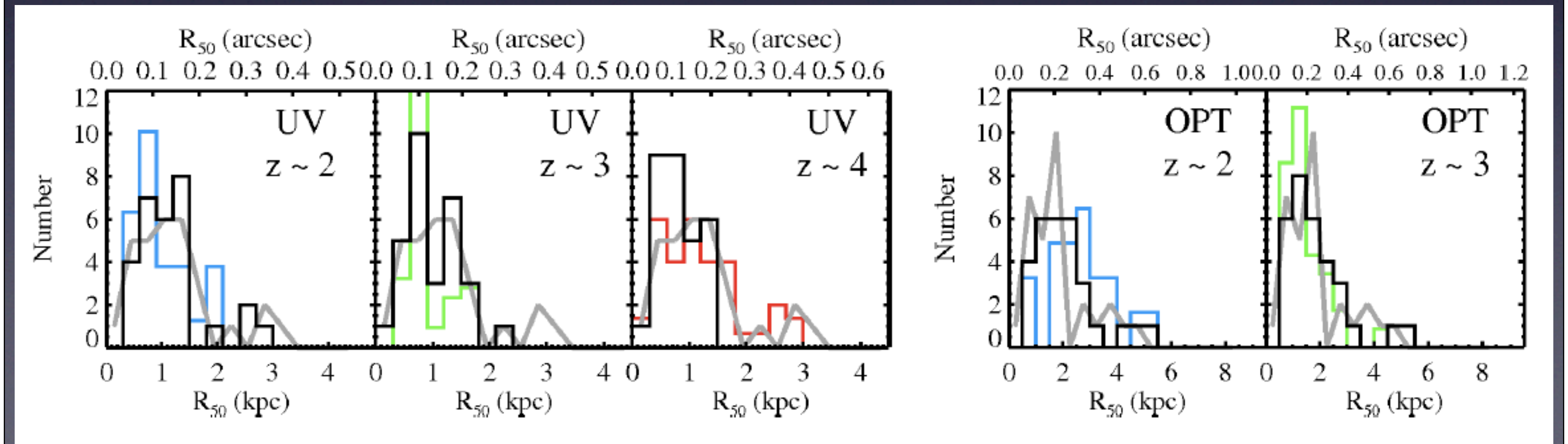
Local and High-z Mass-Metallicity Relation



Compare UV lum (SFR) and UV/optical colours (dust and Age):

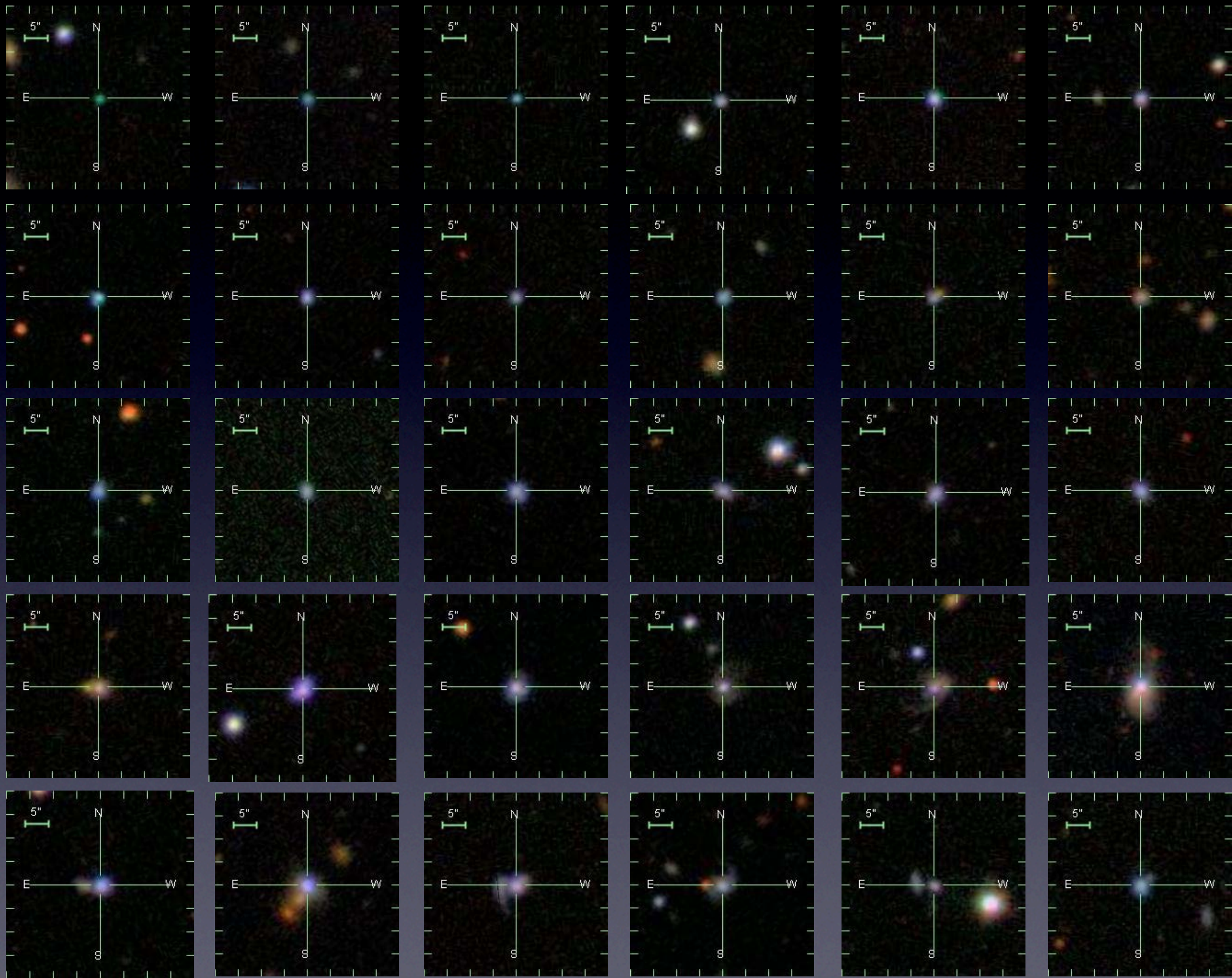


Compare UV/optical Half-light Radii:

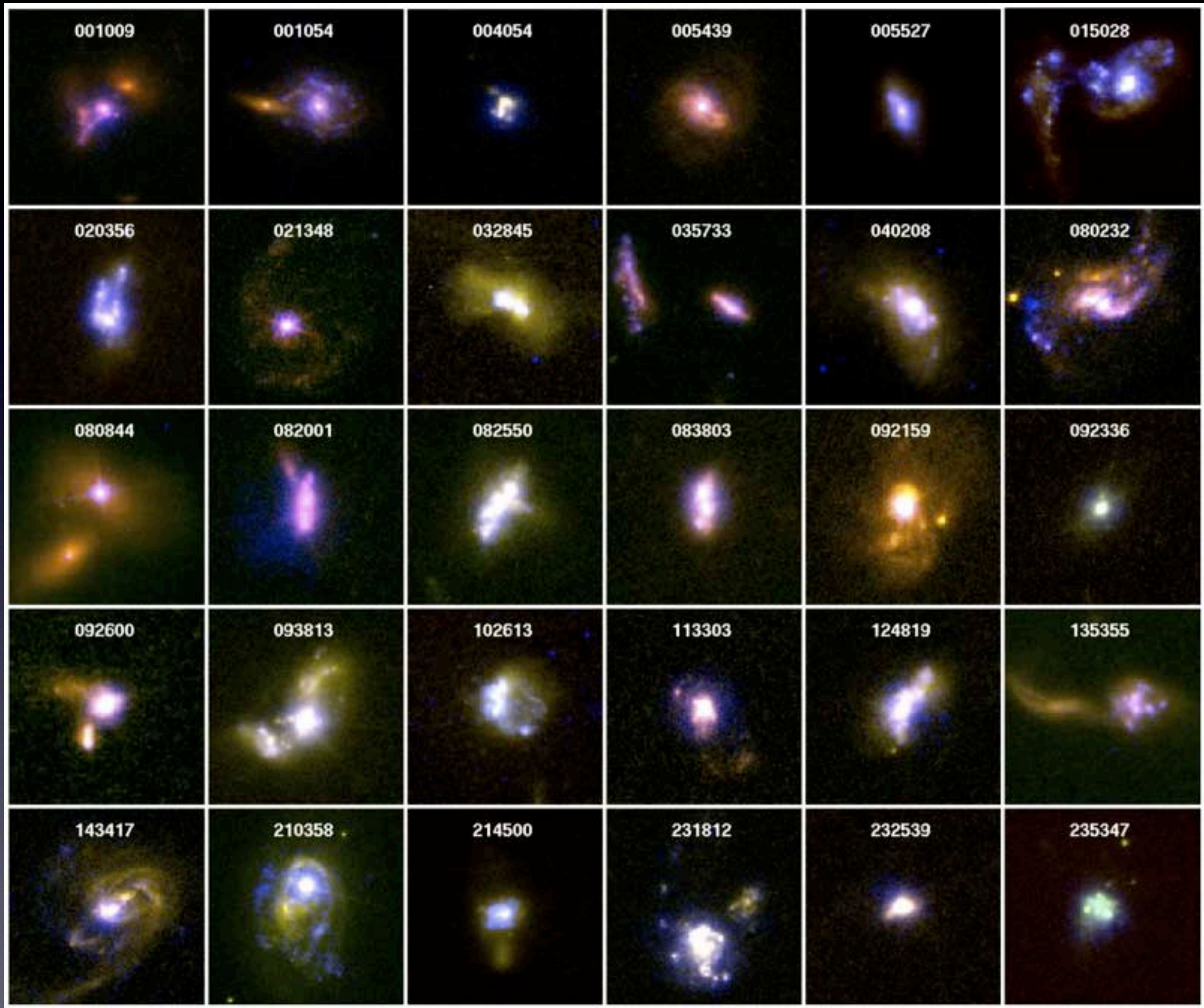


What are they?

SDSS Images mostly unresolved



HST Imaging Program in UV/optical



Some Applications

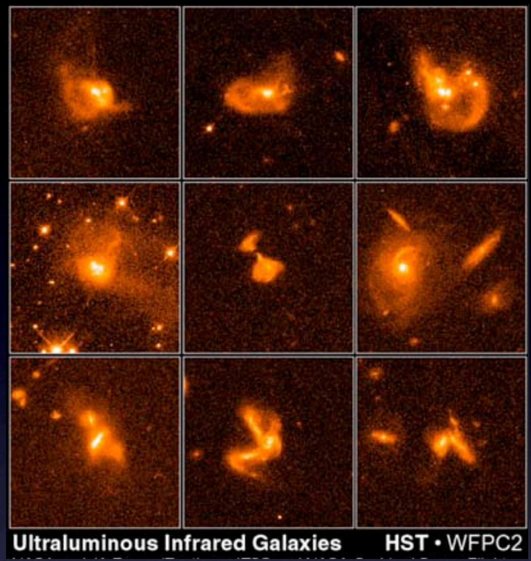
1 Morphologies at high redshift

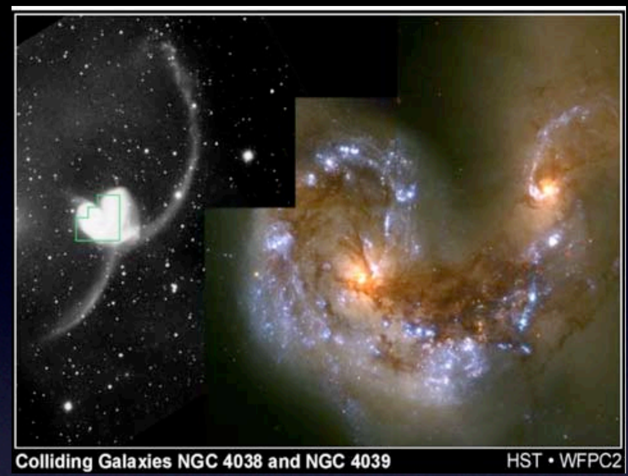
2 Formation of compact nuclear objects

3 Tests of Dust/SFR indicators at High-z

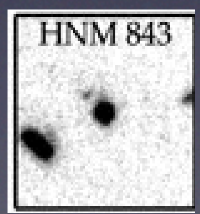
Interactions/mergers as trigger of starbursts at low vs. High redshifts

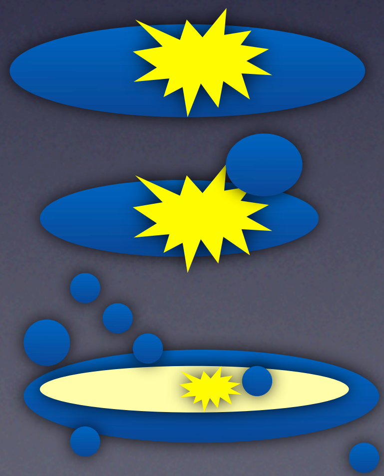
Low-z:

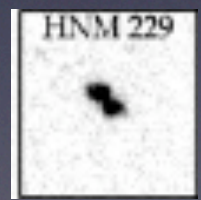


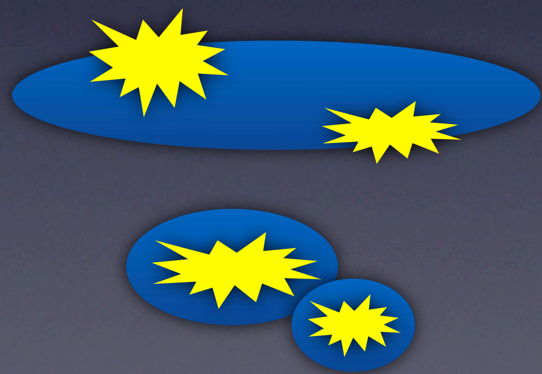


High-z:

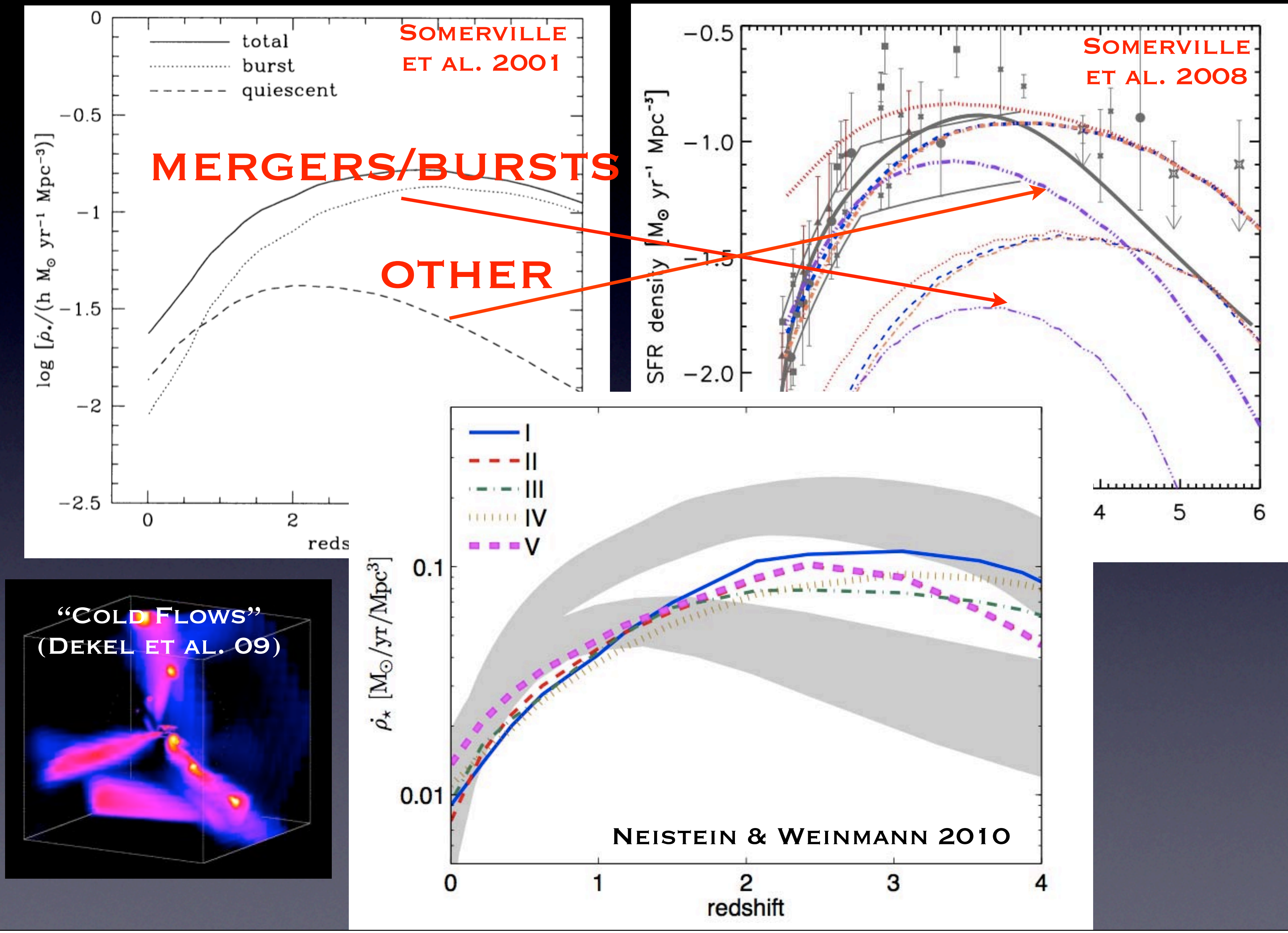




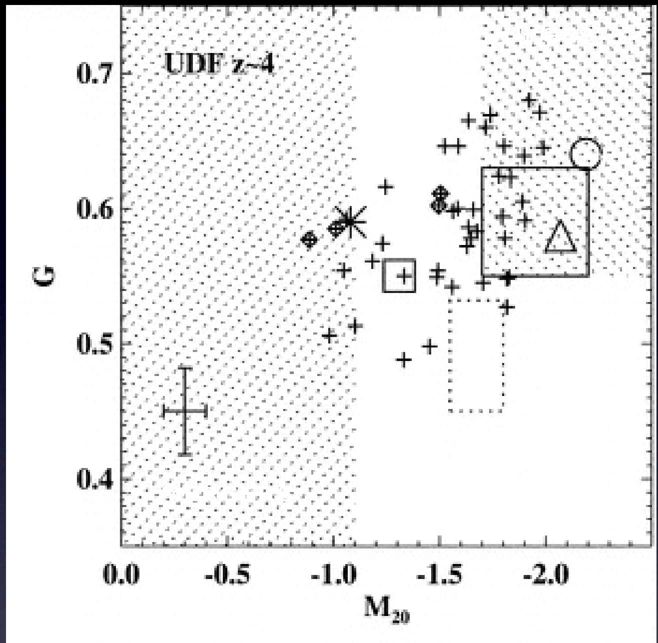


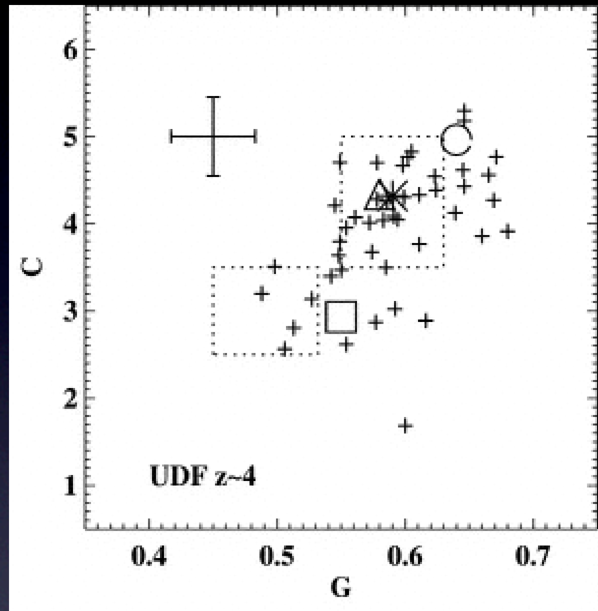


Freedom in Semi-analytic modeling...



UV Morphologies of LBGs typically indicate that they lie in between “spheroids” and “double-nucleated mergers”



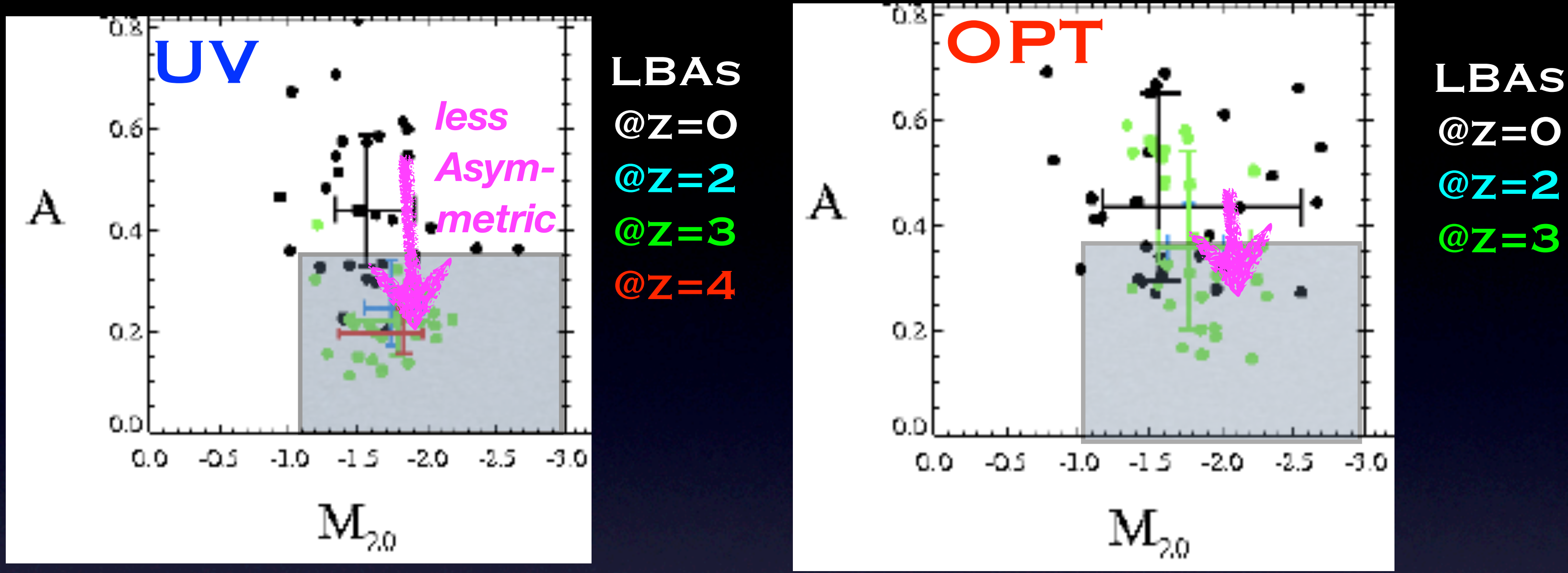


(from Lotz et al. 2004, 2006)

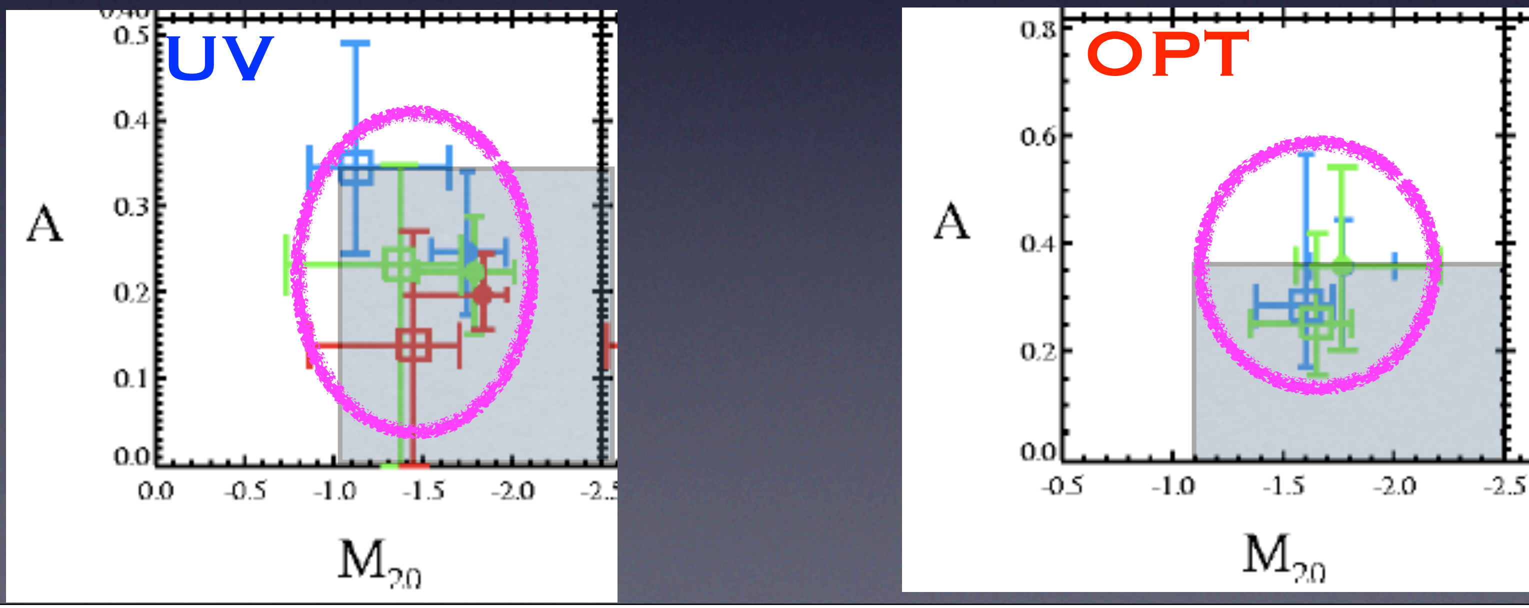
At z=4:

~10-25% double (major merger ?)
~30% spheroidal (bulge ?)
~50% unknown (minor mergers / star-forming disks / merger remnants ?)

Morphologies of LBAs “change” with z:



Redshifted LBAs and LBGs appear quite similar:



Conclusions on Morphologies

Possible Implications:

• large fraction of LBG mergers (and possibly merger-triggered starbursts) may currently be missed even in the deep WFC3 UDF data

Alternatively:

• ***non-merger*** related processes at high redshift drive clumpy star formation at levels similar or higher compared to those only seen in merger-driven LBAs in the local Universe
(e.g., see "clumpy disk" scenario of Elmegreen, Bournaud et al.).

Although, LBG pair counts at z~4 also suggest at least >20-30% mergers (Arnold & Conselice 2009, Cooke et al. 2009)

For the first time we have a suitable sample of UV-selected galaxies that can be used to test the accuracy or the limitations of interpretations of high-z data

[SEE ALSO TALK BY T. GONÇALVES FOR GAS KINEMATICS PERSPECTIVE]

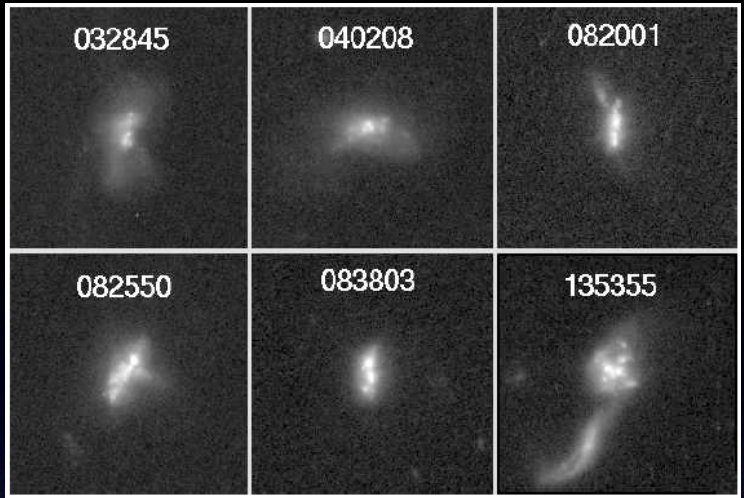
Some Applications

1 Morphologies at high redshift

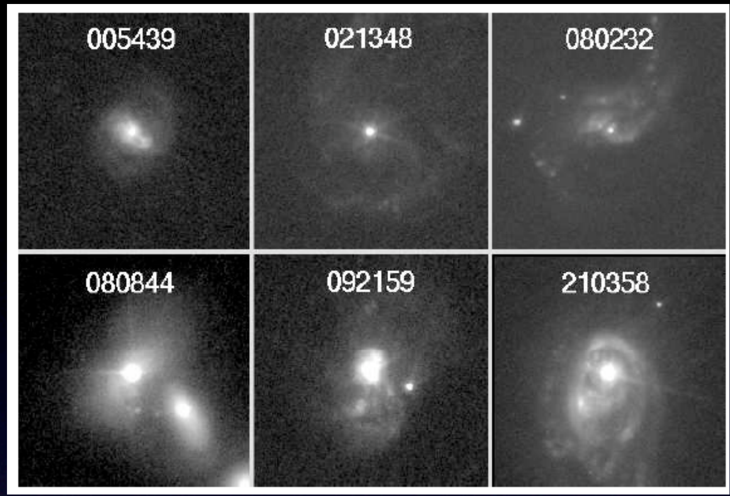
2 Formation of compact nuclear objects

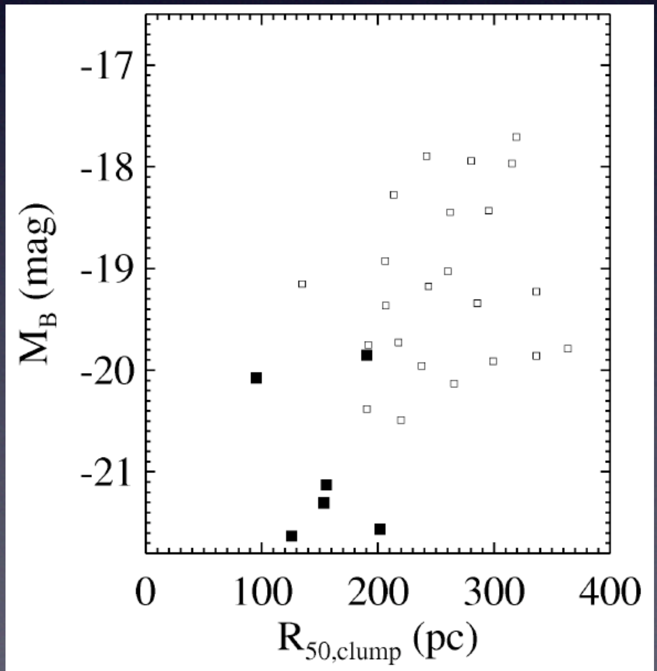
3 Tests of Dust/SFR indicators at High-z

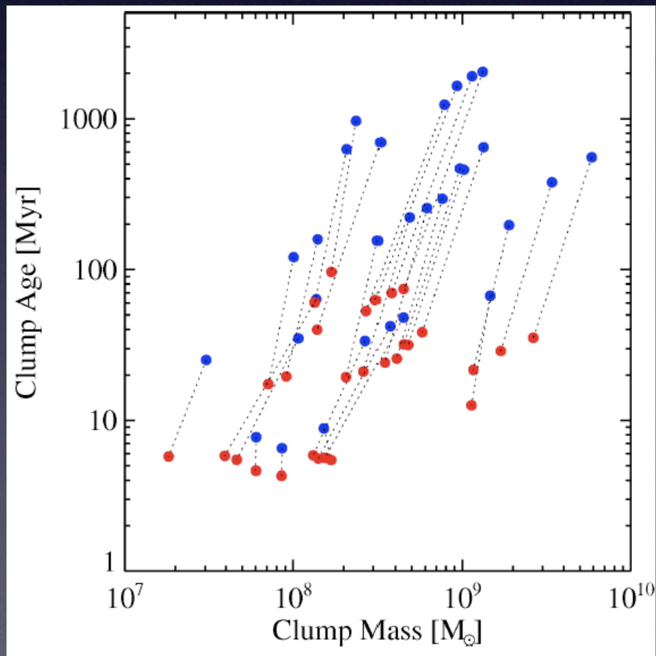
"Dominant Compact Objects" (DCOs)



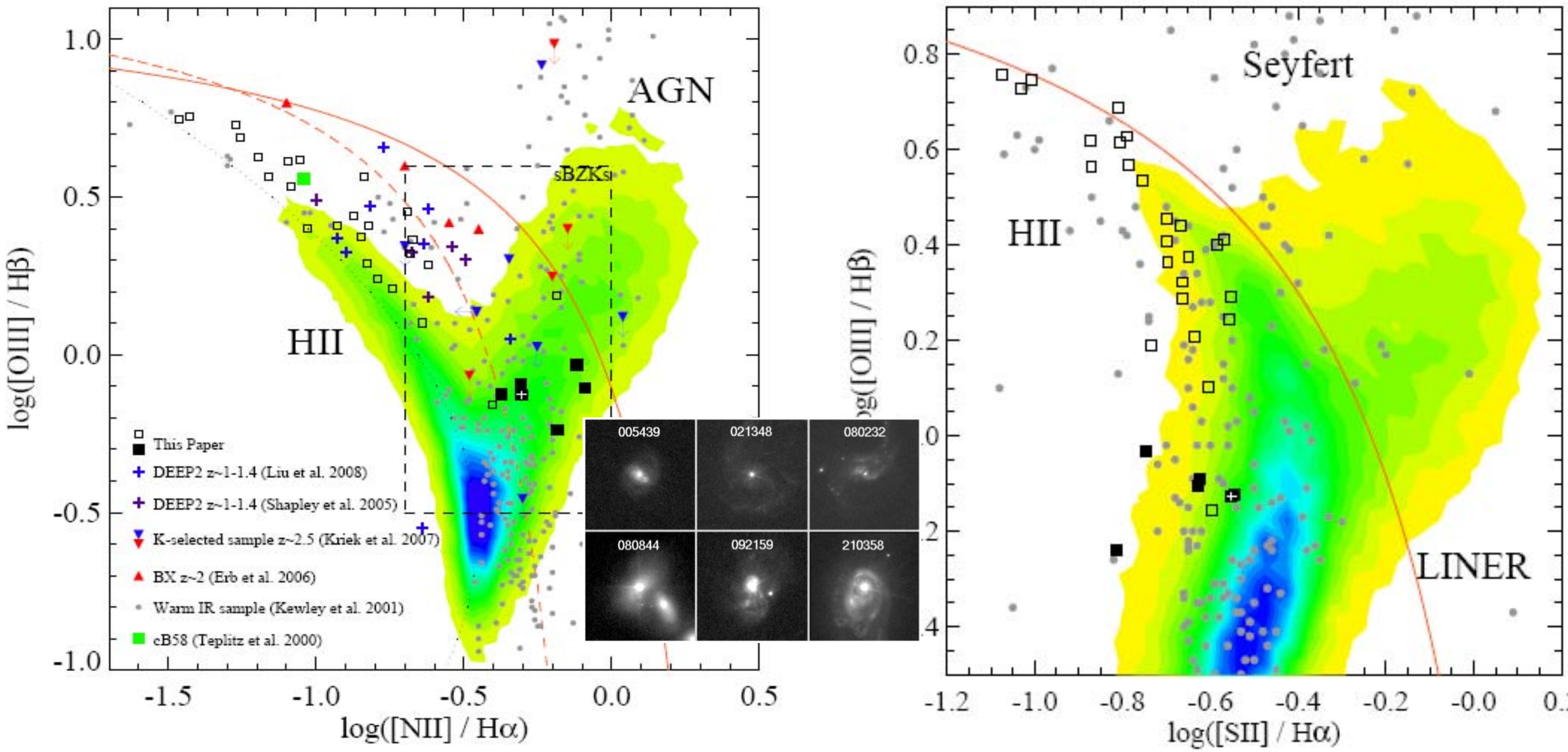
VS







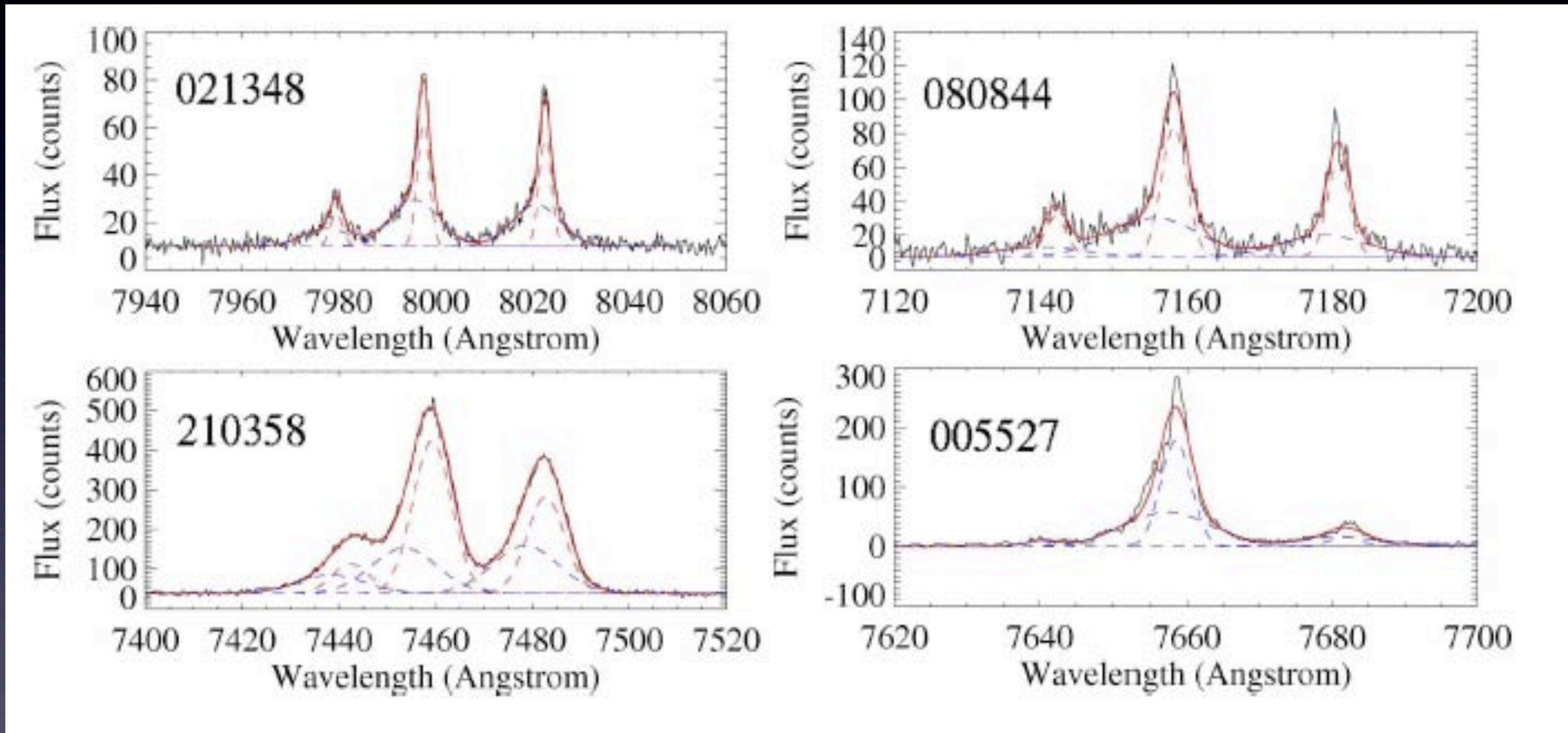
Evidence for Type 2 AGN?



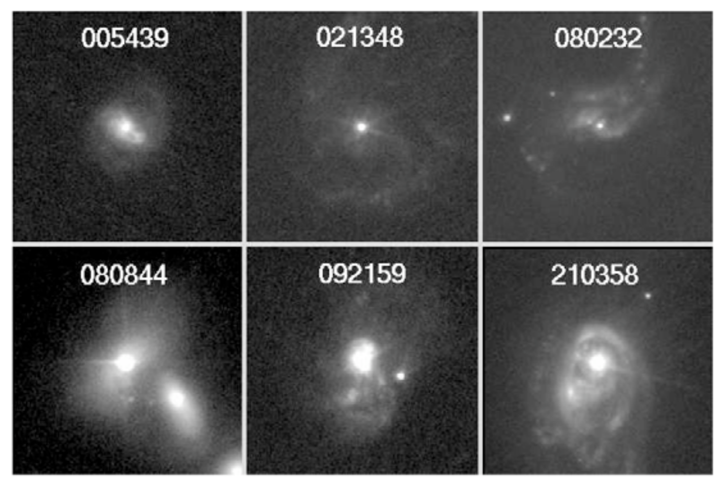
- The DCOs appear to be starburst/AGN composites in standard "BPT" plot
- This is not consistent with other line ratio diagnostics

These are not Type 1 AGN

- VLT spectra: no detectable BLR characteristic of Type 1 Seyfert
- Blue-asymmetric Hα,[NII] lines imply dusty outflows at several hundred km/s



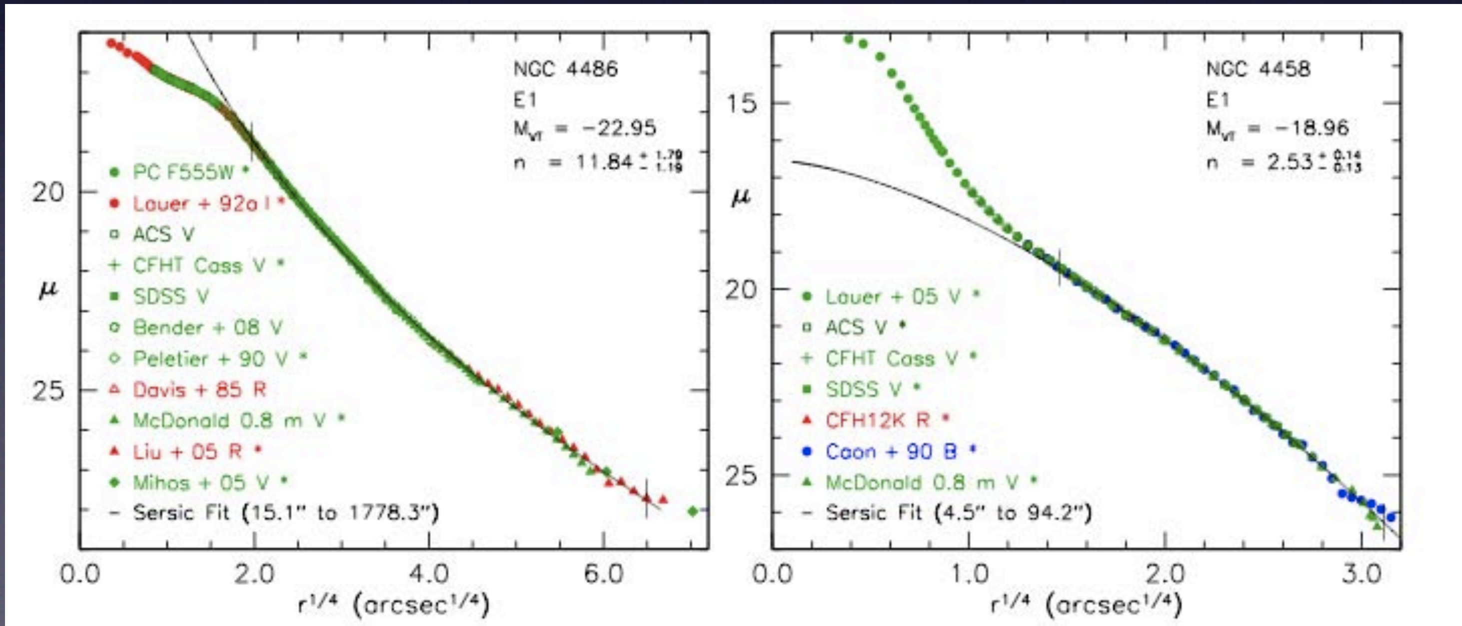
High SN rates in very compact regions lead to high pressures/densities that drive large-scale Galactic winds (common in low and high-z SBs; Lehnert & Heckman 1996, Lehnert et al. 2009, Shapiro et al. 2009)



Witnessing the Forming nuclei of low-mass early-type galaxies (?)

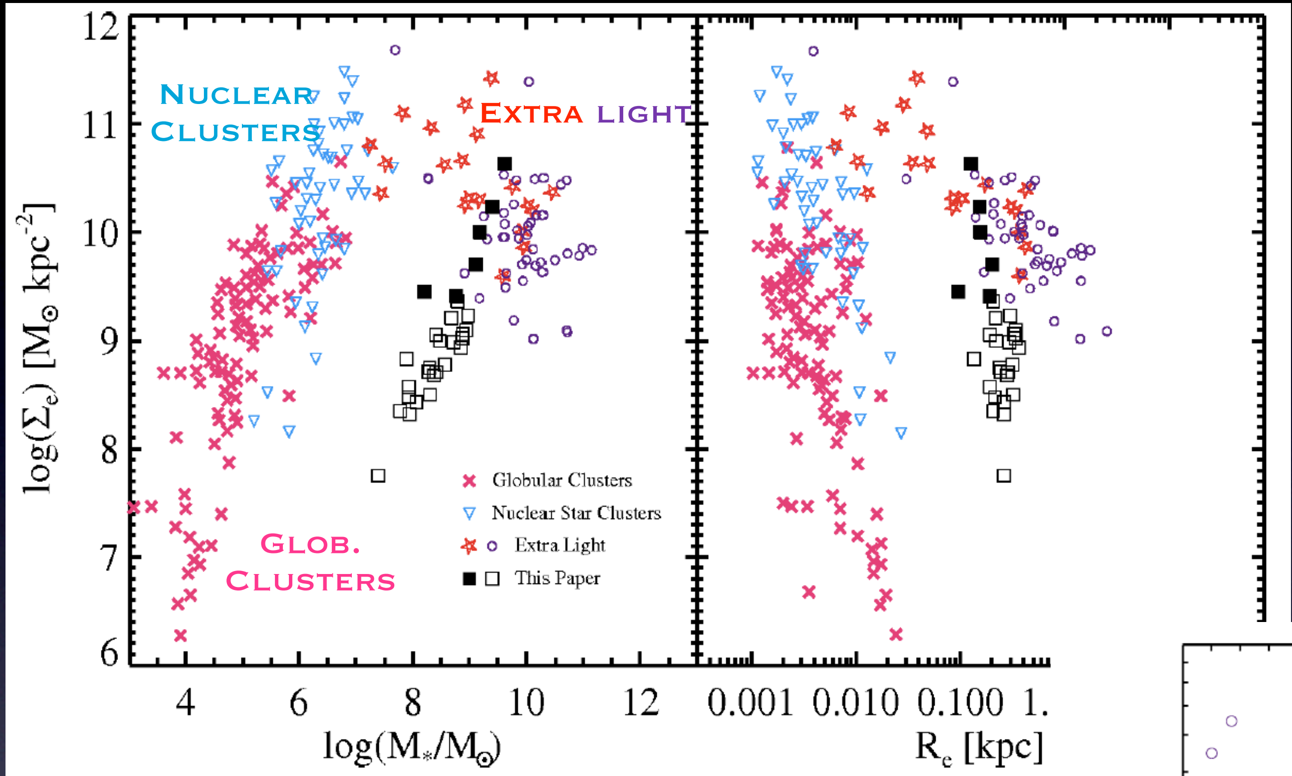
High mass ellipticals have core "deficiencies" > dry mergers

Low mass ellipticals have core "excess" or "cusps" > wet mergers

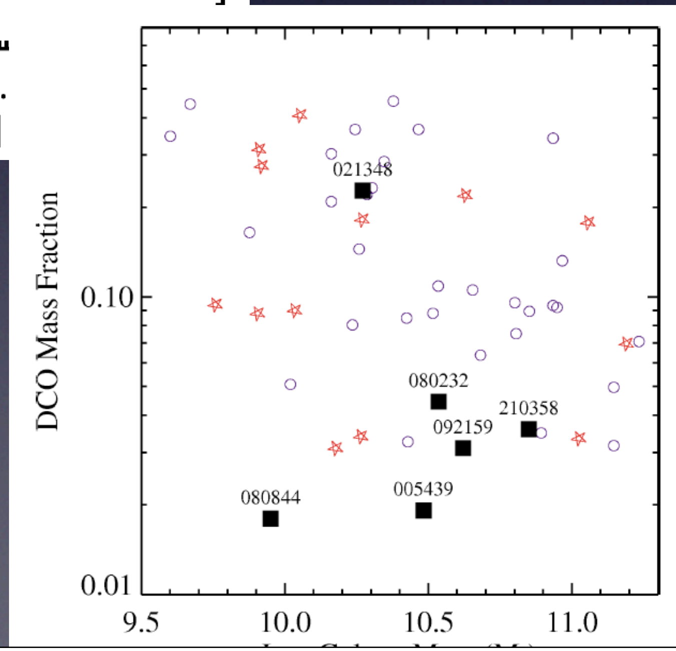


[Kormendy et al. 2008, Hopkins et al. 2009]

Witnessing the Forming nuclei of low-mass early-type galaxies (?)



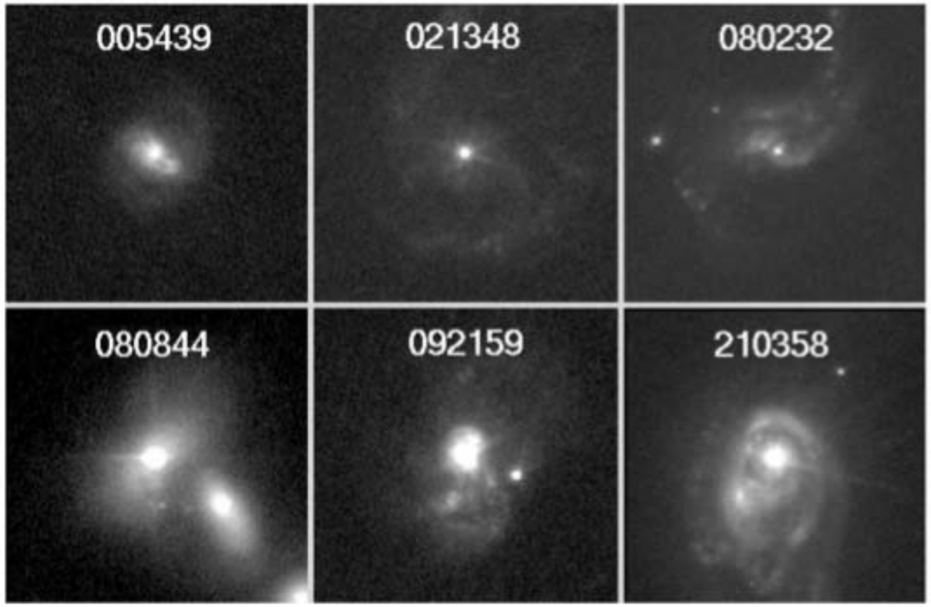
[Comparison data: Hopkins et al. 08/09, Lauer et al. 1995, Kormendy et al. 2008, van Dokkum et al. 2008]



- ✓ Radius ~100 pc
- ✓ Core Mass ~10^9 M_o
- ✓Galaxy mass ~ 5 x 10^{10} M_{sun}
- ✓ Dissipative merger-driven nuclear burst
- ✓ Core/Total Mass ratio ~2-20%
- ✓ Forming outer disk

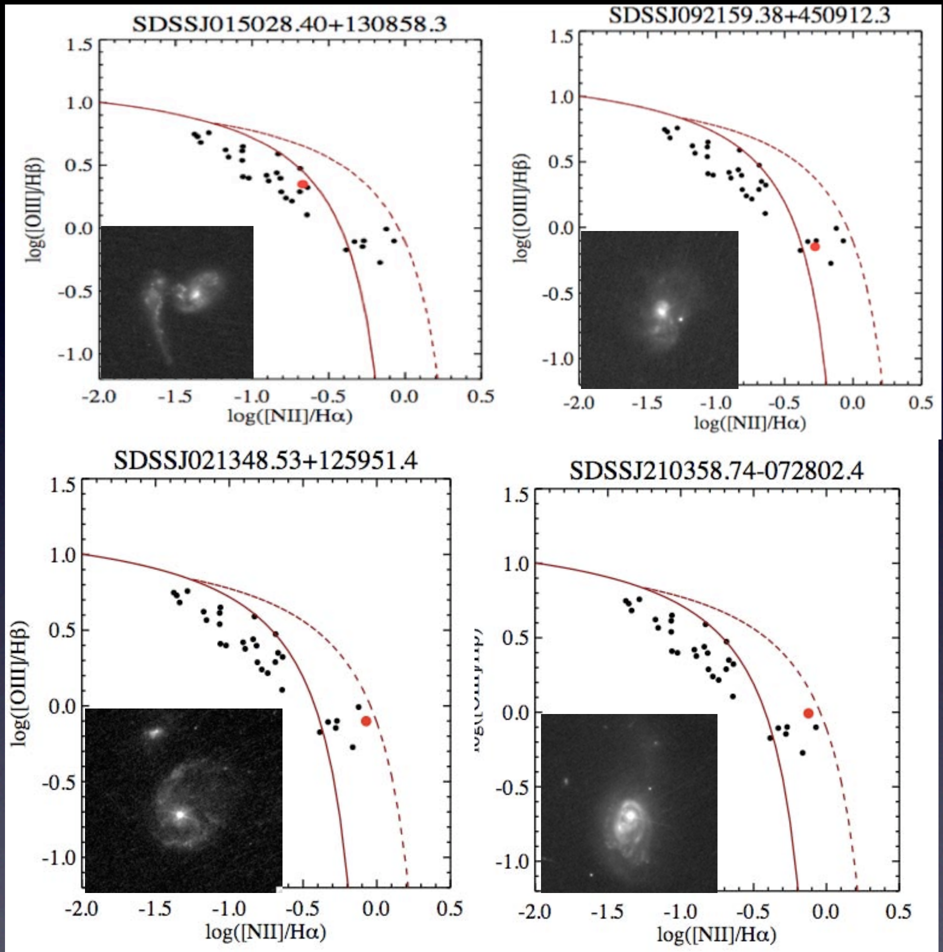
THE FORMATION OF SUPERMASSIVE BLACK HOLES ?

The Dominant Compact Objects



- Sizes ~100 pc, masses of several billion solar masses, young (association with cold dense gas)
- Should be ideal sites for the formation/growth of supermassive BHs

Do we see any ***Direct*** Evidence of low luminosity black holes?
Looking for “compact cores” at 18 cm with the European VLBI (EVN)



TWO DETECTIONS, IN ONE CASE 10X MORE LUMINOUS THAN EXPECTED FROM RSN+SNR

HOWEVER,
TWO OTHER “DCOS” REMAINED UNDETECTED:

Analysis of Chandra X-ray Imaging Program (PI: Ptak) is on-going but not trivial due to resolution, S/N issues

Delayed Central supermassive black hole formation (?)

Local galaxies: tight relation between bulge and SMBH properties.

See Norman & Scoville (1988) Scenario:

- <50 Myr: central gas flow dominated by massive stars & SNIIs
- ~50-100 Myr: dominated by low-velocity outflows from post-AGB stars
- low-velocity gas will not be able to escape a central black hole
- delay time between onset of starburst and BH growth (~100 Myr, e.g. Davies et al. 2007)
- next phase of LBAs is perhaps a dusty SB + luminous AGN

Consistent with high redshift:
AGN fraction is 3% vs. 50% in LBGs vs. sub-mm galaxies
(Steidel et al. 2002, Ouchi et al. 2008, Alexander et al. 2005)

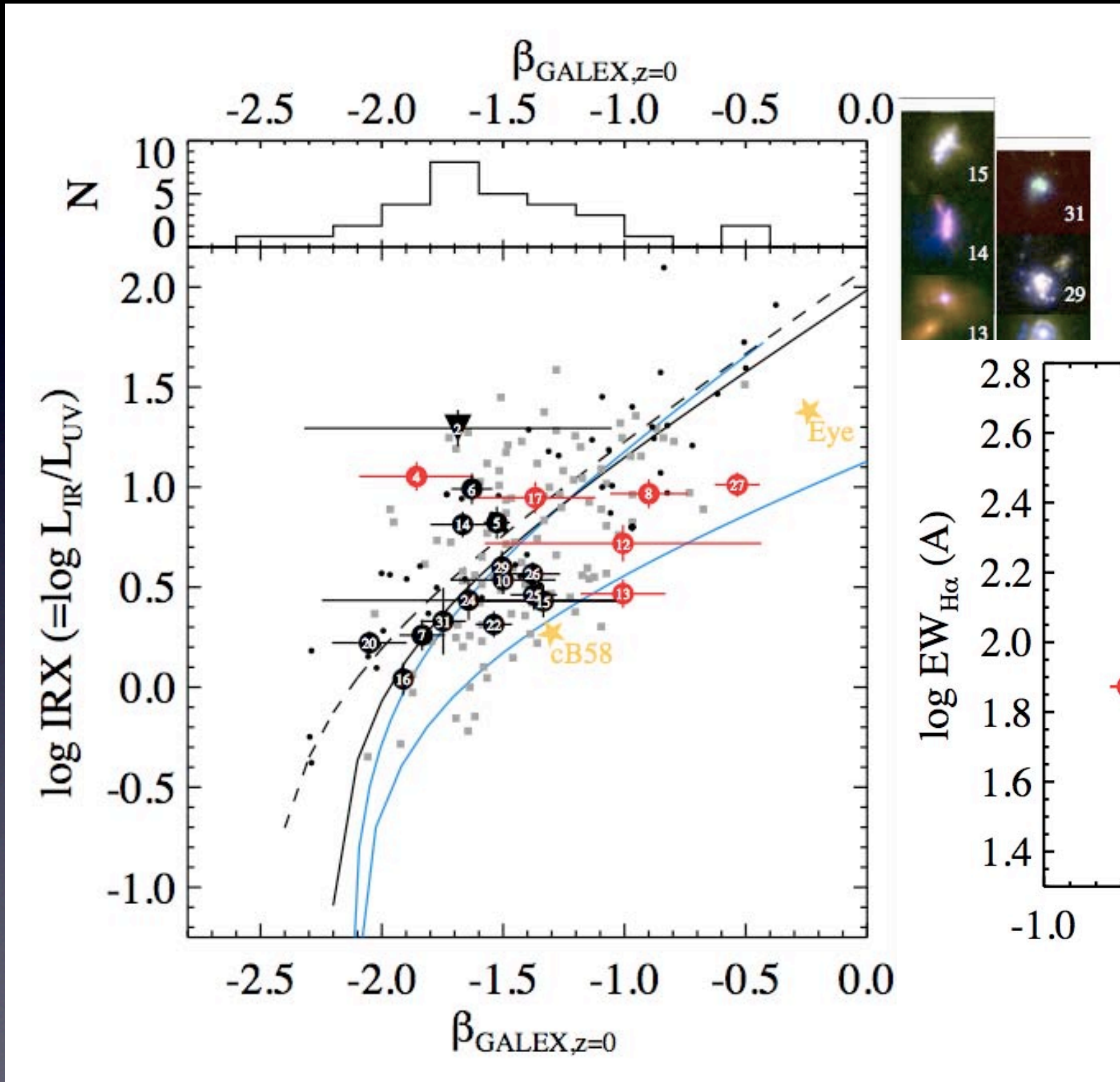
Some Applications

1 Morphologies at high redshift

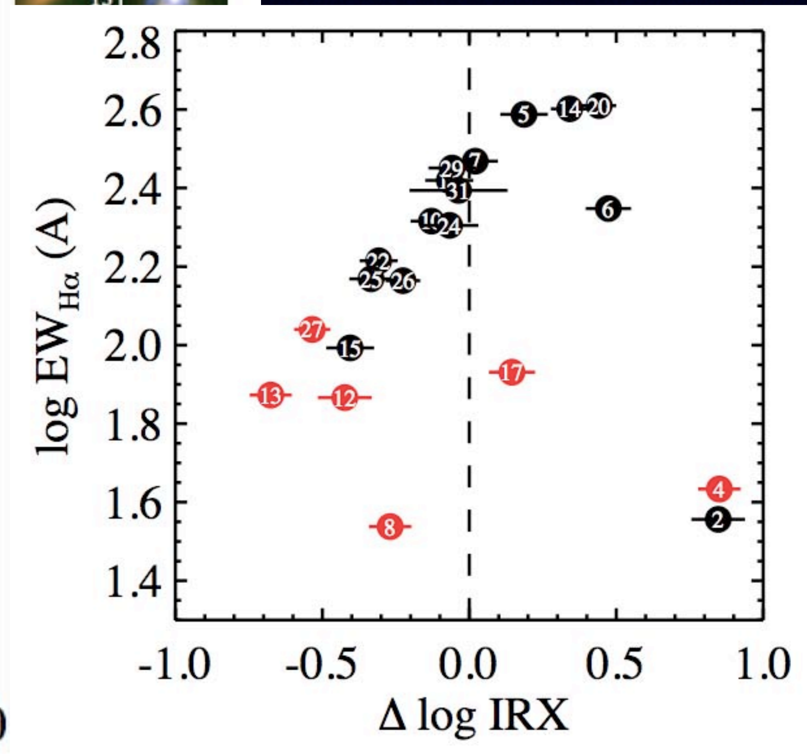
2 Formation of compact nuclear objects

3 Tests of Dust/SFR indicators at High-z

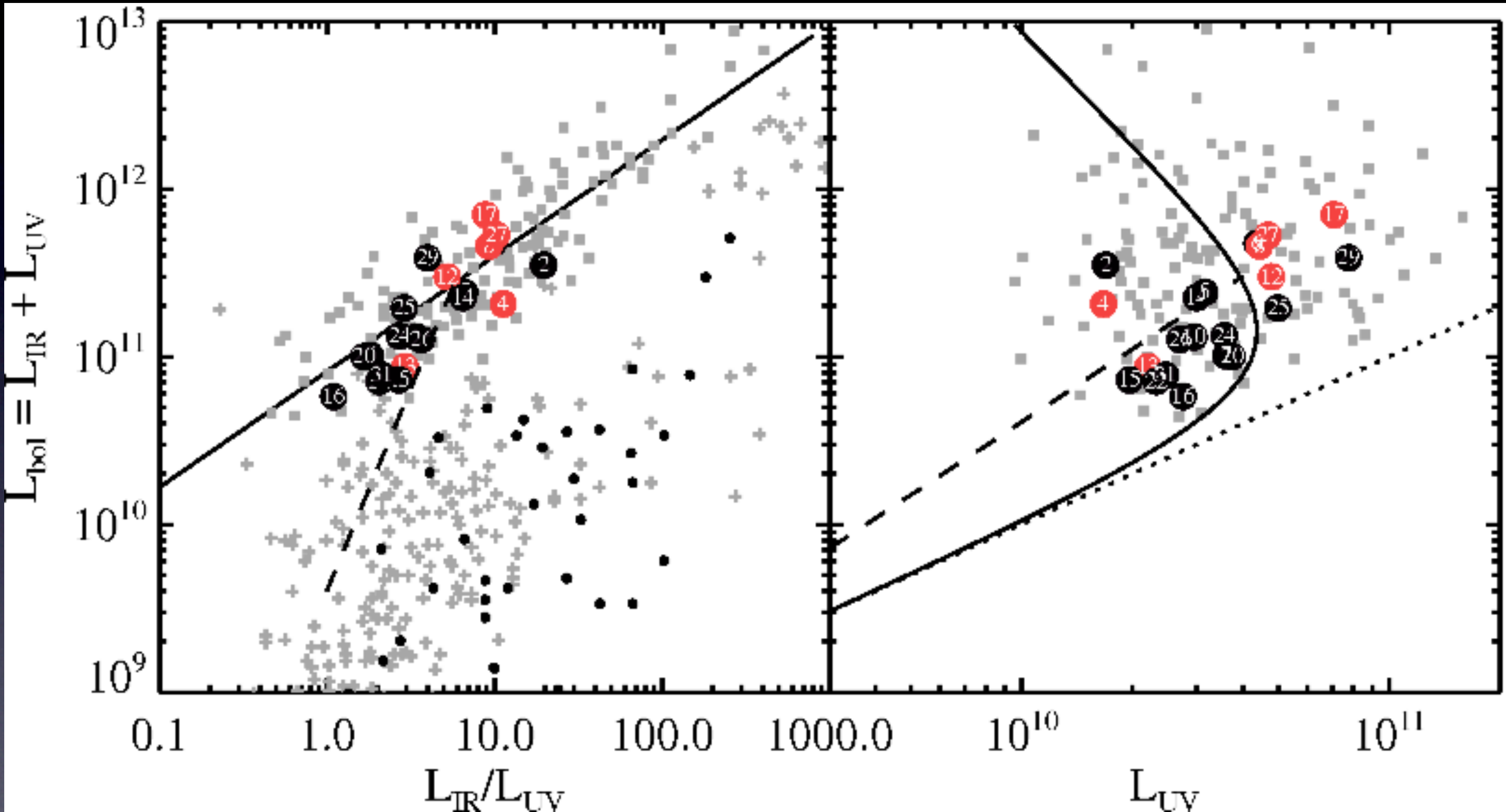
LBAs lie on the β-IRX Relation



IRX ***Offsets***
correlate
with Hα EW:



LBAs have ~10x lower attenuation compared to local Starbursts of the same bolometric luminosities



LBAs can be used to test local SFR calibrations that are widely used at high redshift (in prep.)

Past, Present and Future

Results so far

- GALEX Discovery [Heckman et al. 2005, ApJ, 619, L35; Hoopes et al. 2007, ApJs, 173, 441]
- HST Follow-up I [Overzier et al. 2008, ApJ, 677, 37]
- Morphologies, SFRs, & ISM [Overzier et al. 2009, ApJ, 706, 203]
- Comparison with LBGs in the UDF [Overzier et al. 2010, ApJ, 710, 979]
- VLA radio SFRs/dust [Basu-Zych et al. 2007, ApJS, 173, 457]
- Gas kinematics [Basu-Zych et al. 2009, ApJ, 699, L118; Goncalves et al., See Talk]

Forthcoming

- Relations between SFR, dust, and metallicity
- X-ray analysis of Starburst versus AGN
- VLBI imaging search for low luminosity AGN
- Interpreting morphologies and kinematics at low versus High Redshift

Collecting

- COS FUV spectroscopy (PI: Heckman; Lya, UV escape fraction, weak AGN, IMF, winds)
- XShooter UV+VIS+NIR spectroscopy (PI: RO; Star formation histories)
- GMRT HI observations (PI: RO; Gas masses)
- GTC TTF imaging (PI: Gonzalez-Delgado; Outflows)

Summary

The GALEX/SDSS sample of compact UV-selected galaxies are good analogs of high redshift starburst galaxies in many of their physical or apparent properties

Our program offer a rare, front-row view on the relation between massive starbursts, feedback and the construction of the main components of galaxies (bulges, nuclei, disks, and perhaps “seed” BHs)

LBAs appear to be highly dissipational mergers of gas-rich galaxies

Rest-frame UV images not sufficient for identifying mergers. At high-z, we will need to look for faint tidal features in the rest-frame optical (WFC3 but probably JWST!)

LBAs can be used to optimize SFR calibrations used for LBGs